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Intervention for a multi-character processing deficit in a Greek-speaking child with surface dyslexia.

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Abstract

A case study with a twelve year old boy, RF, who was a monolingual speaker of Greek is reported. RF showed slow word reading and a difficulty in spelling irregular words but not nonwords. Assessments revealed that RF did not appear to have a phonological deficit; but indicated impaired multi-character processing ability for visually presented letter arrays. On the basis of previous research linking multi-character processing and reading (e.g., Bosse et al., 2007) we developed an intervention aimed at improving RF's ability to report letter arrays of increasing length. Following a nine-week programme improvement was observed, and investigation of RF's reading revealed gains in single word reading speed and accuracy. The findings support the significance of intervention studies for testing hypotheses regarding causal relationships among cognitive processes (Nickels et al., 2010) and the notion of specific profiles of developmental dyslexia/dysgraphia in both opaque and transparent orthographies.

Running head: Multi-character processing but not a phonological deficit

Key words: dyslexia; dual-route model; multi-character processing deficit; reading and spelling

Introduction

Developmental dyslexia/dysgraphia is a reading and spelling disorder encountered by children and adults and identified as a difficulty in learning to read and spell (Fletcher, 2009). Research in diverse orthographies has indicated that developmental dyslexia is not only restricted to the English language, although most of the research with dyslexic participants has been carried out in English. The severity of symptoms has been shown to be related to language characteristics, including the consistency of letter-sound relationships (e.g., Hanley, Masterson, Spencer, & Evans, 2004; Gupta & Jamal, 2007). This paper reports a study with a twelve year-old monolingual Greek speaking boy, RF, who exhibited developmental surface dyslexia. Assessment indicated that RF did not have a phonological deficit, rapid naming impairment or difficulty in visual memory. However, he was not able to report letters from briefly presented arrays with the same accuracy as typically developing peers. The significance of the study derives from the fact that a training study was implemented aiming to test a hypothesis regarding the relationship between reading skill and multi-character processing ability, and because case studies investigating the locus of the deficit with Greek speaking developmental surface dyslexic children are rare.

The investigations were based on dual route (DR) models of reading and spelling (e.g., Coltheart, 1981; Barry, 1994), since these have come to be used extensively for single case and case series intervention studies for literacy difficulties (e.g., Broom & Doctor, 1995a 1995b; Rowse & Wilshire, 2007; Kohnen, Nickels, Brunsdon & Coltheart, 2008a). DR models postulate that two routes or sets of processes are used by competent readers and spellers. Whole-word lexical processes deal effectively with irregular or exception words (such as: *vehicle or εκκλησία:*

/eklisia/ (church)) and familiar words, using a store of lexical orthographic units. Sublexical processes deal effectively with novel items and low frequency regular words, using stored phoneme-grapheme/grapheme-phoneme correspondence rules.

In what follows we first discuss characteristics of the Greek writing system and then focus on research that has looked at possible causes of poor reading and spelling performance. We then outline the rationale for the present study and describe investigations of the locus of RF's literacy difficulties and an intervention programme that he took part in.

The Greek writing system is transparent for reading, with almost one-to-one grapheme-phoneme correspondences; however, the situation for spelling is rather different. The irregularities primarily derive from the fact that although pronunciation has changed from antiquity, spelling has remained the same. Thus, as Harris and Giannouli (1999) note, Greek spelling is based on the etymology of the words rather than their current pronunciation. There are many written words containing different graphemes representing the phonemes /o/, /i/ and /e/, since certain phonemic distinctions (e.g., between vowels represented by <η, ι, υ, οι, ει, υι> and those represented by <ο, ω>) are no longer present in the language. Nunes, Aidinis and Bryant (2006) point out that these inconsistencies in Greek lie in the context of a system that is otherwise highly consistent, unlike the situation for English. In addition, the alternative spellings for the vowels are governed by morpho-syntactic rules (such as the first person of verbs ending with the vowel grapheme <–ω> /o/, while nouns end with <–ο> /o/). Children are taught these rules in the early years of formal schooling, and most children master correct spelling by Grade 3.

Turning now to possible causes of poor reading and spelling it is difficult to suggest a single aetiology. It has long been held that the core deficit in dyslexia relates to phonological processing, particularly the ability to manipulate speech sounds, to perform tasks tapping verbal short-term memory (such as digit span and nonword repetition) and lexical retrieval (such as rapid automatized naming) (for a comprehensive account see Wagner & Torgesen, 1987; Snowling, 2001; Snowling & Rack, 1991; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wolf & Bowers, 1999; Papadopoulos, Georgiou, & Kendeou, 2009; Georgiou, Protopapas, Papadopoulos, Skaloumbakas, & Parilla, 2010). A child with developmental dyslexia, based on research evidence, might have difficulty with all or just some of these functions. Evidence in favor of phonological processing being the core component in reading and spelling achievement derives from training studies (e.g., Bradley & Bryant, 1983; Goswami & Bryant, 1990) and longitudinal studies (e.g., Caravolas, Hulme, & Snowling, 2001). However, the causal relationship between phonological processing and reading attainment has been questioned (for a review see, Castles & Coltheart, 2004) and has come to be challenged in recent years (Vidyasagar & Pammer, 2010).

Research looking at visual memory deficits as an alternative potential cause for developmental reading difficulties has been reported. For example, Goulandris and Snowling (1991) assessed JAS, a developmental dyslexic who appeared to have intact performance in tasks tapping phonological awareness (PA) and processing but poor performance in reading irregular low frequency words, as well as a spelling impairment. She exhibited a deficit in visual memory as assessed in a task involving presentation of arrays of unfamiliar symbols (Greek letters). The authors suggested that the visual memory deficit may have led to a difficulty in forming detailed orthographic representations. Romani, Ward, and Olson (1999) reported AW, an adult developmental dysgraphic. AW’s poor performance with irregular words was attributed to poor encoding of serial order, as reflected in poor performance in a visual sequential memory task.

Studies have also examined the role of visual processing deficits in developmental dyslexia\dysgraphia (see Boden & Giaschi, 2007, for a comprehensive account). Although there is research indicating visual temporal processing problems in developmental dyslexia (Farmer & Klein, 1995), it has been debated whether these larifyWimmer, 2006). Ramus and Ahissar (2012) in a review of data on normal and poor performance in dyslexic participants claim that magnocellular dysfunction (problems with the ability to process fast changes in the visual modality, Livingstone et al., 1991) and sluggish attention shifting (a slowing of attention engagement/disengagement, Hari & Renvall, 2001; Facoetti et al., 2010; Lallier et al., 2009, 2010) tend to co-occur with phonological problems.

Bosse, Tainturier, and Valdois (2007) found in a large cohort of dyslexic children that some of the participants showed a selective difficulty in a letter report task while others exhibited a phonological deficit. They used global report and partial report versions of the letter report task. In the former, all the letters in the array are reported, while in the latter a bar probe is presented after the array to request report of just one letter. Bosse et al. interpreted their findings within the connectionist multi-trace memory model of polysyllabic word reading of Ans, Carbonnel, and Valdois (1998). According to this, skilled reading involves both global and serial, analytic processing. Poor performance in the letter report task was interpreted as reflecting a reduction in visual attention span. It was suggested that this would affect global processing and would lead to especial difficulty reading irregular words (e.g., *yacht, mortgage*), since acquisition of orthographic recognition units for irregular words is particularly dependent on simultaneous processing of all the letters in a word. This reduction in the visual attention span window, according to the researchers, could be characteristic of developmental surface dyslexia. In addition, the participants would produce mainly regularization errors in reading as analytic processing would be unimpaired. In contrast, within this model, a phonological deficit would affect analytic processing, and consequently non-word reading, leading to developmental phonological dyslexia.

In subsequent work by Dubois et al. (2010) directed at understanding the deficit underlying the reduced span, the researchers presented evidence from two case studies with developmental dyslexia. On the basis of this investigation, the researchers suggested that a range of deficits could be responsible for deficient performance in letter report tasks and put forward as potential candidates a) the slow uptake of letter information, b) a limitation of the number of elements that can be extracted from a briefly presented array and stored in visual memory, and c) an imbalance of spatial attentional distribution.

Ziegler, Pech-Georgel, Dufau, and Grainger (2010b) investigated the possibility that poor performance in letter report tasks was associated specifically with verbal stimuli. They employed both alphanumeric stimuli and non-verbal stimuli (for example, /, }) in a forced choice visual span task. The performance of dyslexics did not differ from that of control children with non-verbal stimuli; however, there was a significant group difference with alphanumeric stimuli. On this basis the researchers argued that the letter report task that has been used by Bosse et al. involves a phonological component, and that dyslexics actually suffered from a visual-to-phonology mapping deficit. Specifically, Ziegler et al. argued that digits and letters, but not other symbols, produce impaired performance in dyslexia, as dyslexics have difficulties in accessing phonological representations in long-term memory.

Valdois, Lassus-Sagosse, and Lobier (2012) conducted two experiments in order to evaluate the explanation put forward by Ziegler et al. (2010b). In the first experiment they used tasks involving naming of arrays of letters, digits, and colour patches. The latter stimuli were considered to be of low familiarity and as a consequence more difficult to name, as it is not usual for children to name arrays of colour patches. They found that for colour patches, report performance of both dyslexic and non-dyslexic children dropped significantly, indicating that visual processing of unfamiliar stimuli has a detrimental effect on performance of both groups. They also found that the dyslexic children performed worse than the non-dyslexic children for letter and digit report but not for colour report. Valdois et al. argued that since all three tasks (letter report, digit report and colour report) involve nameable stimuli then if the visual-to-phonology mapping deficit explanation of poor performance in multi-character processing tasks was correct then dyslexics should have been impaired in all three tasks. In the second experiment a different group of dyslexic children and chronological age matched controls performed report tasks with letters, both with concurrent articulation and without. In line with prediction, the performance of the dyslexic group was worse than that of the control group, but critically, this was independent of concurrent articulation, indicating that performance in the letter report task is not reliant on this particular component of phonological processing.

Lobier, Zoubrinetzky and Valdois (2011) also challenged the notion that performance in the letter report task is related to phonological ability by employing a verbal and a non-verbal visual categorization task. They found that performance in the letter report task correlated with performance in both verbal and non-verbal categorization tasks, contrary to predictions from the visual-to-phonology code mapping hypothesis.

Impaired letter report performance has been described in case studies and has been related to lexical processing deficits/surface dyslexia. Valdois, Bosse, Ans, Carbonnel, Zorman, David, and Pellat (2003) reported the case of Nicholas, a 13 year old boy with impaired letter report and the characteristics of surface dyslexia and surface dysgraphia. They also reported a boy with phonological dyslexia, who did not exhibit a deficit in letter report. Valdois et al. (2011) described a case of a nine-year-old boy, Martial, who exhibited severe mixed dyslexia (poor reading of irregular words and nonwords) and surface dysgraphia. Valdois et al. tested Martial with global and partial report tasks. Martial was found to have impaired global report performance but there was no evidence of difficulty in partial report. However, when performance in partial report was broken down according to letter position it was found to be atypical. The association of surface dyslexia/dysgraphia and impaired letter report performance is relevant to the present study since, as will be reported later, we argue that RF's reading and spelling difficulties can be characterized as developmental surface dyslexia/dysgraphia, and he showed poor performance in global letter report.

Currently then, research does not seem to favour a single cause for dyslexia/dysgraphia. As noted above, different patterns of deficit have been reported in case studies of developmental phonological and surface dyslexia/dysgraphia (e.g., Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride & Peterson, 1996; Valdois et al., 2003), although a number of authors have argued that the evidence for these discrete subtypes is contentious, or else can be explained in terms of individual differences in terms of instruction or intervention (see for example, Bryant & Impey, 1986; Wilding, 1990; Thomson, 1999; Sprenger-Charolles & Serniclaes, 2003; Stanovich, Siegel, & Gottardo, 1997). More recent research confirms that the manifestation of literacy deficits varies according to the characteristics of writing systems, such that a phonological deficit might not be so profound in the case of transparent orthographies. Ziegler, Bertrand, Tóth, Csépe, Reis, Faísca, et al. (2010a) found that the significance of phonological awareness as an indicator of literacy difficulties depends on the transparency of the orthography, being more significantly related to reading/spelling skill in opaque orthographies than transparent ones. Also, Caravolas, Volin, and Hulme (2005) showed the need for more difficult or timed phonological awareness tasks for readers of transparent orthographies, in order to detect an effect of phonological ability on reading skill. Ziegler et al. argued that as reading accuracy approaches ceiling in transparent orthographies (as shown in several cross-linguistic studies, e.g. Hanley et al. 2004) reading speed is a more sensitive index of reading difficulty.

The current investigation

In one of the relatively small number of detailed investigations of cases of developmental dyslexia/dysgraphia in Greek, Douklias, Masterson, and Hanley (2010) reported cases of phonological and surface developmental dyslexia in Greek. They assessed 84 poor readers aged 9-12 years and identified four cases who showed selective reading difficulties. Two of the children exhibited poor nonword reading accuracy, which the authors argued was due to problems with the development of sublexical processes, and characteristic of phonological dyslexia, and two exhibited slow familiar word reading, a pattern that the authors suggested was due to problems in development of lexical processes and equivalent to surface dyslexia. Douklias et al. predicted that the cases with surface dyslexia would show a significant difficulty spelling irregular words but not nonwords (due to lexical impairment but normally developing sublexical processes), while phonological dyslexia in Greek would be associated with the opposite pattern of spelling difficulty (due to sublexical impairment). These predictions were supported in the four cases. In addition, the two children with a profile of phonological dyslexia exhibited worse performance in phonological awareness tasks than age matched control children. One of the two children with the profile of surface dyslexia did not show impaired performance in the phonological awareness tasks. However the other child with this profile was worse than controls in phoneme and syllable deletion, indicating a mild phonological deficit. Finally, both children with the profile of surface dyslexia showed worse performance in rapid naming (RAN) tasks than control children, while the phonological dyslexics were unimpaired in these tasks. Douklias et al. speculated, in line with previous suggestions of Manis et al. (1999) that RAN deficits and surface dyslexia may reflect the same underlying deficit – one that involves a difficulty in forming arbitrary associations, such as those that must be learnt between irregular words and their pronunciations. In the present study we used several of the tasks employed by Douklias et al. to see whether the pattern of performance exhibited by RF, the child described in the present paper, might conform to either of the profiles identified in the Greek-speaking poor readers. We investigated phonological ability, RAN, visual memory, print exposure and letter report in relation to RF's reading and spelling performance.

Once we had identified a difficulty in letter report as a potential locus of the reading deficit in RF we carried out an intervention study aimed at improving letter report performance. One of the goals of our study was to examine whether any improvement in letter report as a result of the intervention might be accompanied by an improvement in tasks considered to be associated with lexical processing. If this was found to be the case then it would provide support for the hypothesis linking multi-character processing ability and lexical processing. Nickels, Kohnen, and Biedermann (2010) recently highlighted the significance of intervention studies in informing theories of cognitive processes. Indeed there have been several such studies (e.g., De Partz, Seron, & Van Der Linden, 1992; Nickels, 1992; Rapp & Kane, 2002; Biedermann & Nickels, 2008a, 2008b; Brunsdon et al., 2005; Kohnen, Nickels, Coltheart, & Brunsdon, 2008b; Kohnen, Nickels, Brunsdon, & Coltheart, 2008a; Kohnen et al., 2010). A good deal of evidence derives from studies of people with acquired dyslexia and dysgraphia, for example, Rapp and Kane (2002) investigated treatment of spelling in relation to improving the capacity of the graphemic buffer, and Biedermann and Nickels (2008a, 2008b) investigated whether or not homophones have independent representations by means of intervention studies.

Further intervention studies have been conducted with children with developmental dyslexia and dysgraphia. These have involved targeting the potential locus of the reading or spelling deficit, that is, training in grapheme-phoneme rules in the case of developmental phonological dyslexia, or improving word-specific knowledge in the case of developmental surface dyslexia. For example, Brunsdon et al. (2005) conducted a study with a twelve year old child who had developmental surface dyslexia. The authors targeted the spelling of irregular words in the intervention. Kohnen et al (2008b) followed up the results reported by Brunsdon et al., conducting an intervention study with a nine-year-old child with developmental surface dyslexia. Improvement in both studies was found for treated and untreated irregular words. The authors discuss the results in terms of strengthening of connections between lexical entries and the graphemic buffer. Two studies, conducted by Kohnen et al. (2008a) and Kohnen et al. (2010), targeted improvement of sublexical spelling skill in two developmental dyslexics with mixed dysgraphia. The authors reported that intervention resulted in long-lasting improvement in spelling of both trained and untrained items, and generalization to reading skill was observed.

Intervention case studies targeting either the lexical or the sublexical route with developmental dyslexics with mixed dyslexia have also been conducted. Brunsdon et al. (2002) carried out a study with a child aged 10-years-old with severe reading and spelling difficulty that targeted reading and was aimed at improving lexical processing. The intervention resulted in improvement of word, but not nonword, reading skill and gains were sustained over time. The researchers also reported generalisation to untrained items and to spelling.

The above brief review shows that single case training studies can be employed as a means of informing models of cognitive processes, and also as a means of producing evidence for techniques that have positive clinical outcomes. In the following sections we report our investigations of the possible causes of case RF's literacy difficulties, and we describe the intervention that he took part in that targeted letter report performance. The training studies with children with reading and spelling difficulties reviewed above directly addressed impaired reading/spelling processing while in the training study with RF, a potential distal cause of the reading impairment was targeted.

Case study

RF was aged 12:08 and attending a state school in Greece when the study was carried out. He had one sibling, a younger brother who, based on his parents' report, was a precocious reader (he learned to read when he was four-years-old on his own). RF's developmental history was uneventful and milestones were attained at the appropriate ages. RF's mother tongue was Greek and this was the only language spoken by his family. RF's parents were both educators, working in secondary education, teaching modern and ancient Greek. No one in RF's family had reading or spelling difficulties. RF had not been able to learn to read and write when he was in the first grade of school, despite support from his parents and a private tutor. The private tutor did not follow a phonics-based programme, according to RF's parents. At the end Grade 2 he was still reading by means of syllabifying words (a technique typically used by children in the very initial stages of learning to read). RF's reading and spelling difficulty led his parents to look for further help. When RF was ten years old he was assessed by the Greek educational department responsible for assessing children and adolescents with reading and spelling difficulties. The assessment concluded that RF had developmental dyslexia.

At the time the current assessments began, i.e., when RF was 12:08, his parents reported that his reading and spelling were very poor and that his reading was so laborious that he could not follow subtitles on the television screen (many programmes on Greek television are imported from abroad and presented in their original language with subtitles). RF's slow reading was of great concern to his parents as he had problems comprehending difficult school subjects without having someone read them aloud. RF had received additional help from a tutor for the subject Ancient Greek during the course of the school year. The tutorial help involved working on homework assignments. This was the only additional help he had had since the private tutor in Grade 1.

The following background assessments were administered and the results are given in Table 1. Non-verbal reasoning ability was assessed using the Matrix Analogies Test (Naglieri, 1985) and arithmetic ability with the subtest of the Wechsler Intelligence Scale for Children-III (WISC III, Georgas et al., 1997). Verbal short-term memory was assessed with the digit span subtest of the WISC-III. The Peabody Picture Vocabulary Test, adapted for Greek by Simos, Sideridis, Protopapas, and Mouzaki (2011), was administered in order to assess receptive vocabulary. For this test normative data are not available. Four monolingual Greek speaking typically developing readers/spellers from the same school as RF were recruited to serve as a comparison group. The comparison group consisted of two boys and two girls (mean age: 12;06, s.d.=0;06, range 12;03-13;06) matched in age and non-verbal ability to RF. These children served as the comparison group for the background assessments reported in Tables 1 and 2 and for assessments reported in Tables 9 and 10 later. A different group of eleven children matched to RF for age and non-verbal ability served as a comparison group for the detailed assessments and in the one-minute nonword reading task reported in the next two sections (mean age of the comparison group children was 12;03, s.d.=0;05, range 11;09-13;06). Modified t-tests (Crawford & Howell, 1998) were used for all the assessments reported in the paper to compare RF's scores with those of the comparison groups. Where there were significant differences these are marked in the tables with asterisks (*p* values reported are 1-tailed).

"(Table 1 about here)"

Reading and spelling assessments

Standardised measures

The Reading Test Alpha (Panteliadou & Antoniou, 2007) is a standardized reading test and was used for the assessment of aspects of RF's reading. The test measures four components: 1) reading comprehension, 2) morphological and syntactic awareness, 3) text reading rate and 4) single item reading accuracy. Test-retest reliability for all tasks ranges between .74 and .87. The reading comprehension measure involves reading texts and responding to multiple choice questions, and morphological awareness involves, for example, filling in the gap in sentences with the appropriate grammatical form of a provided word. Reading rate is assessed using a text and involves recording the total number of words read in one minute. Reading accuracy involves two subtasks: reading aloud words and nonwords and lexical decision. The reading aloud subtask involves the presentation of a printed list of 53 words (mean number of letters = 10.5, s.d.=3.3) and 24 nonwords (mean number of letters = 9.6, s.d.=3.1). The words and nonwords are intermixed and of increasing difficulty, according to the test manual. The lexical decision subtask involves 20 words (mean number of letters = 6.1, s.d.=1.1) and 16 non-words (mean number of letters =7.1, s.d.=1.8) presented intermixed in nine printed arrays (of three, four and five items in each array). The child is asked to read through the arrays silently and to report to the tester which of the items are words. The overall score for reading accuracy in Test Alpha consists of number of items read correctly in the reading aloud subtask plus number of words and nonwords correctly identified as such in the lexical decision task.

For spelling, RF was assessed with a single word spelling-to-dictation test developed by Mouzaki, Protopapas, Sideridis, and Simos (2007), and with a text production sub-test that assesses spelling ability and coherence (Porpodas, Diakogiorgi, Dimakou, & Karantzi, 2007). According to Mouzaki et al. single words for the spelling-to-dictation task (mean number of letters=7.6, s.d.=2.9) were chosen from primary school reading primers and they included a wide range of morpho-syntactic rules. Words chosen were prone to morphological and orthographic errors, in cases where the testee did not know the appropriate spelling of the vowel grapheme. In the text production test children are asked to produce a piece of written prose based on four related pictures (Porpodas et al., 2007). Two scores are provided. The first, spelling ability, involves dividing the number of correctly spelled words in the text by the number of misspellings multiplied by 100. The second score, for coherence, involves assigning points to categories based on the depth of information given. Test-re-test reliability is .79 for the spelling ability assessment and .57 for coherence.

Experimental measures

In order to obtain a measure of lexical and sublexical reading skill we used the single words and nonwords from the Reading Test Alpha reading accuracy measure on a separate testing occasion ten days after the other components of Test Alpha had been assessed. We assessed single word and nonword naming latency and accuracy by presenting the items on the computer[1] in blocks, with the nonwords presented first followed by the words. Nonword stimuli were presented first following the administration procedure of a recently developed reading test that assesses lexical and sublexical skills (the Diagnostic Test of Word Reading Processes, FRLL, 2012). Stimuli were presented centered on the screen of a Dell Inspiron portable lap-top with Windows 7. Font was Consolas size 14. Vocal reaction times were extracted from the sound files using the *Checkvocal* programme developed by Protopapas (2007). In order to be consistent with the Douklias et al. study, the latencies were calculated in milliseconds from the time the stimuli appeared until RF provided a verbal response (threshold was set at 60 dB). Only correct responses were included in calculating the means.

An additional reading assessment was devised to obtain a measure of nonword reading rate, comparable to the measure used in the Reading Test Alpha for obtaining text reading rate. Stimuli comprised 50 nonwords ranging in length from five to 16 letters (mean number of letters=10.8, s.d.=2.4). The items had the same inflectional endings as nouns and were devised by reversing the syllables of real words in order to create pronounceable nonwords. A list of the nonwords can be found in the Appendix. RF was asked to read as many nonwords as possible in one minute.

Table 2 reports the results of statistical testing for the key reading and spelling tasks against the results of the typically developing comparison group. RF showed poor performance in the standardized measures of text reading rate, $t(4)=10.8$, $p<.001$, $r=.98$, reading accuracy, $t(4)=18.6$, $p<.0001$, $r=.99$, single word spelling, $t(4)=5.2$, $p<.01$, $r=.87$ and spelling in text, $t_{spelling}(4)=12.8$, $p<.01$, $r=.99$, $t_{coherence}(4)=6.2$, $p<.05$, $r=.95$. On the experimental measures RF was impaired in single word naming latency, $t(4)=3.2$, $p<.05$, $r=.85$, and accuracy, $t(4)=9.1$, $p<.001$, $r=.97$. Qualitative analysis of RF's spelling errors revealed that the majority (93%) were phonologically plausible. Phonologically plausible misspellings were considered to be those that contained existing phoneme-grapheme correspondences in Greek. Examples of RF's phonologically plausible errors are *πετάνε*-> πεταναι: /petane/ (they throw), *πηγή*-> πιγη: /piyi/ (fountain), *αυτοκίνητο* ->αυτοκήνιτο /aftokinito/ (car)).

“(Table 2 about here)”

Summary of assessment results

The background assessments revealed that RF showed no evidence of deficits in non-verbal reasoning, verbal short-term memory or receptive vocabulary, and that he had a score in the very high ability range for arithmetic. Tests of reading and spelling showed no significant deficits in the areas of reading comprehension, morphological awareness, or nonword reading. Deficits were found for text reading rate, text reading accuracy, single word reading accuracy, single word naming latency, single word spelling, and spelling in text.

As noted in the Introduction, slow word reading, poor irregular word spelling, and lack of evidence of a phonological deficit were associated with the profile of developmental surface dyslexia in Greek poor readers by Douklias et al. (2010). Since slow word reading was identified in the initial testing with RF we decided to examine for further indications of the surface dyslexia subtype with detailed assessments reported in the next section.

Detailed assessments

RF was first administered a test of irregular word and nonword spelling to dictation. The detailed testing also involved assessments of phonological ability, rapid naming, print exposure, sentence-printed word matching with homophones, visual memory, and letter report.

Spelling of irregular words and nonwords

The word and nonword stimuli were taken from the study of Loizidou-Ieridou, Hanley and Masterson (2009), who had selected the items to investigate spelling development in Greek-speaking children. There were 20 irregular words and 40 nonwords. Half the items in each set were short (two to three syllables) and half were long (four to five syllables). Irregular words were those in which the vowel should be spelled with a grapheme that deviated from the predominant phoneme-grapheme correspondence. Half the irregular words were low frequency (mean=0.38, s.d.=0.35) and half were high frequency (mean=32.54, s.d.=64.50) according to values from the Greek frequency database (GREEKLEX, Ktori, van Heuven, & Pitchford, 2008). The nonwords and irregular words were presented for spelling to dictation in blocks, with non-words presented first as nonword spelling is less demanding in comparison to regular and irregular words. Each irregular word was read aloud by the tester and then provided in the context of a sentence for disambiguation. The results are given in Table 3. For irregular word spelling RF was significantly less accurate than the comparison group, $t(11)=7.1$, $p<.0001$, $r=.90$. By contrast, for nonwords, RF's accuracy was not significantly different from that of the comparison group, $t(11)=0.0$, $p=0.5$. Qualitative analysis of RF's spelling errors showed that, as in the standardised spelling assessments reported above, almost all errors (98%) were phonologically plausible.

"(Table 3 about here)"

Phonological ability and rapid naming

The blending subtest from the standardized Athena Test battery (Paraskevopoulos et al., 1999) was used. Since this battery is for children aged up to age ten, and RF was twelve years old, more demanding phonological ability assessments were also administered. One was a spoonerisms task, adapted from the Phonological

Assessment Battery (Frederickson, Frith, & Reason, 1997) for English-speaking children, and one was a word reversal test adapted from a task developed by De Pessemier and Andries (2009). In the former, the first phonemes of two spoken words must be switched (e.g., *γάτα* /yata/ (cat) – *φίλος* /filos/ (friend) will become *φάτα /fata/ – γίλος* /yilos/). In the second task, children have to judge if the second of two spoken stimuli is a reversal of the first or not (e.g., *υπολογιστής /ipoloyistis/(*computer*)–σητσιγολοπυ* /sitsiyolopi/). RF performed three practice trials for both tasks and the time needed to complete all the pairs (12 in each task) was measured with a stopwatch.

Rapid automatized naming was assessed with the picture and digit naming subtasks of the Phonological Assessment Battery (Frederickson et al., 1997) and also with a letter sound naming test devised for this study. Six lowercase high frequency letters (α, κ, π, λ, ε, σ) were used for this task. Results for RF and the comparison group in all the tasks are given in Table 4. RF's performance did not differ significantly from that of the comparison group except for in spoonerisms, where RF's time to complete the task was faster than that of the comparison children, $t(11)=1.9$, $p<.05$.

"(Table 4 about here)"

Print exposure

Stanovich and colleagues (1997) suggested that developmental surface dyslexia may be due to lack of exposure to print. We investigated this possibility in RF's case with two print exposure tests based on those developed by Cunningham and Stanovich (1992). An author and a book title recognition task were devised, suitable for Greek-speaking children of RF's age. We found that RF's scores for title recognition (10/25 correct) and author recognition (9/25 correct) did not differ significantly from those of the comparison group (comparison group mean correct=8.82, s.d.=3.3 for title recognition, t=0.34, p>.05; comparison group mean correct=9.50, s.d.=5.1 for author recognition t= 0.09, p>.05).

Sentence-printed word matching with homophones

Sentence-printed word matching tasks with homophones included in the distractors have been considered to be a measure of lexical orthographic processing, that is, of the ability to access word recognition units in the lexical system, as well as of the integrity of these units themselves. Thus, for example, Hagiliassis Pratt, and Johnston (2006) argued that homophone verification can be used as a measure of orthographic processing, independent of phonology, since accurate recognition of the correct spelling of a word against its phonologically identical foil cannot be based solely on phonology. English-speaking surface dyslexics have been reported to make high rates of homophone choice in this type of task (e.g., Weekes & Coltheart, 1996; Brunsdon et al., 2005), and this has been interpreted as due to reliance on sublexical processes.

The task developed for RF involved 40 target homophones. On each trial RF was presented with a sentence spoken by the tester and a choice from among four printed stimuli. The choices comprised the target homophone, the homophonic mate of the target, a pseudohomophone of the target, and a word visually similar to the target (e.g., target homophone: *μηλιά* (apple tree) /milja/, homophonic mate: *μιλιά* (human talk) /milja/, pseudohomophone: *μοιλιά* /milja/, and visually similar word: *φιλιά* (kisses) /filja/). Results for RF and the comparison group are given in Table 5.

"(Table 5 about here)"

RF's performance differed significantly from that of the comparison group, $t(11)=4.5$, $p<.0001$, $r=.80$. The majority of his errors (83%) consisted of choice of the homophonic mate of the target. Choice of the pseudohomophone of the target and the visually similar distractor represented 8% of errors each. This is in accordance with the results for English-speaking surface dyslexics in terms of the high rate of homophonic mate choice.

Visual memory

Four tasks were used to assess visual memory as follows.

i) Memory for pictures and designs

Two subtests from the Athena Test (Paraskevopoulos et al., 1999) were used, Memory for Designs and Memory for Pictures. These require reproduction (using cards provided by the tester) of a series of abstract designs (in the case of Memory for Designs) or familiar pictures (in the case of Memory for Pictures) following a five second retention interval. The number of items presented increases throughout each subtest. The number of trials in each subtest is nine. Testing begins with three cards presented on each trial and goes up to six cards. The testee has two opportunities to provide a correct response at each array length, the first is scored with 2 points the second with 1, and after two consecutive incorrect responses at a particular array length the test is discontinued. Correct responses are considered those where the test items are reproduced in the correct order.

ii) Visual simultaneous and sequential memory

The simultaneous visual memory task was adapted from the one described by Hulme (1981). The current task used Arabic characters (which acted as unfamiliar symbols for RF). Arrays of 2, 3 or 4 characters were presented on the screen of a DELL

Inspiron computer for 10 seconds each. A test array was then presented after a retention interval of 1 second for the first six trials, and after 10 seconds for the following six trials. The test array contained the characters in a different order and intermixed with two new characters. RF was asked to report the characters, in correct order, by pointing on the screen. There were three practice trials.

The sequential visual memory task employed characters from Tamil and Devanagari and was an adaptation of the task used by Goulandris and Snowling (1991). On each trial 2, 3 or 4 characters appeared sequentially on the computer screen for 2 seconds per character. As in the simultaneous visual memory task, a test array was then presented following a retention interval of 1 second for the first six trials and 10 seconds for the following six trials. RF was asked to select the characters in the correct order from a test array of characters intermixed with two distractor characters.

For both tasks items had to be recalled in the correct order for the trial to be counted as correct. The characters for the simultaneous and sequential memory tasks were presented in font size 80 and the tasks were designed in PowerPoint for Windows 7. The results for the visual memory tasks for RF and the comparison group are presented in Table 6. RF's performance differed significantly from that of the comparison group only for Memory for Pictures, $t(11)=2.2$, $p<.05$. In this task he performed significantly better than the comparison group.

"(Table 6 about here)"

Letter report

Greek letters were used to develop equivalents of the tasks used by Bosse et al. (2007) to assess multi-character processing. Both global and partial letter report were assessed. For global letter report, on each trial RF was asked to name all the letters in the array of five letters. In partial letter report he was asked to report a single letter from the array of five letters, with the target indicated by a cursor. Global and partial report tasks were presented as blocked sessions, with global report first. Letter strings appeared in uppercase (Consolas 14) in the center of a computer screen for 200ms. A Dell Inspiron lap-top with Windows 7, and video mode 1366x768 at 60Hz was used. The letters Γ, Δ, Θ, Λ, Ξ, Π, Σ, Φ, Ψ were employed. As the task was also used to test bilingual Greek- and English- speaking children (Niolaki, Masterson, & Terzopoulos, 2013) we aimed at avoiding letters common to the two orthographies. This resulted in the use of Greek letters with relatively low frequency of occurrence (mean of 8,489, while the letters that we did not include had a mean frequency of 12,309 according to Ktori et al., 2007). As Greek letter names are not frequently used, RF and the comparison group were asked to respond with either letter sounds or letter names, choosing whichever they found easiest. RF and all the comparison group children responded with letter sounds.

For the global report task, participants were asked to name as many letters as they could identify. Number of letters correctly reported and number of total arrays correctly reported were recorded (irrespective of whether letters were reported in the correct order or not).

The comparison group for the letter report tasks consisted of eight typically developing readers/spellers matched to RF in age and non-verbal ability (mean age=12;05, s.d.=0;05, range 11;09-13;06). The children were a sub-sample of the eleven children who acted as the comparison group in the other assessments reported. Table 7 gives the results. For global report, RF showed a marked impairment in the task, $t_{arrays}(8)=3.58$, $p=.004$, $r=.78$ and $t_{total\ letters}(8)=5.32$, $p=.001$, $r=.88$. For partial report RF's performance was comparable to that of the comparison group.

"(Table 7 about here)"

Valdois et al. (2011) used a control task of single letter identification in their study in order to investigate potential visual processing difficulties for letters. An equivalent task was devised for RF. The nine letters used in the letter report tasks were presented singly in the center of the computer screen for five different presentation durations (33 msec, 50 msec, 67 msec, 84 msec and 101 msec). RF and the comparison group children were asked to name them immediately when they appeared. Prior to letter presentation a central fixation point appeared for 1000 msec, and at the appearance of the letter a mask (13 mm high and 37 mm wide) appeared for 150 msec. The results for single letter identification are given in Table 7. RF's accuracy and naming times did not differ significantly from those of the comparison group.

For the global and partial letter report results we examined the effect of letter array position on accuracy for RF and the comparison group. The results are presented for global report in Figure 1a and for partial report in Figure 1b. The global report profile of the comparison group was characterised by a linear function, $F(1,8)=60.08$, $p<.001$, $\eta^2=.88$, and this was also the case for RF. At positions 1, 2 and 3, RF was significantly less accurate than the comparison children (correct Position 1 for RF=17, comparison group mean=19.75, s.d.=.46; $t_{P1}(8)=5.63$, $p<.0001$, correct Position 2 for RF=16, comparison group mean=19.63, s.d.=0.51; $t_{P2}(8)=6.58$, $p=.001$, and correct Position 3 for RF=9, comparison group mean =18.25, s.d.=1.2; $t_{P3}(8)=6.71$,

p=.0001). For positions 4 and 5 the difference approached significance (correct Position 4 for RF=9, comparison group mean=14.25, s.d.=2.8; $t_{P4}(8)=1.77$, p=.06, correct Position 5 for RF=8, comparison group mean=13 s.d.=2.8; $t_{P5}(8)=1.68$, p=.06).

"(Figure 1 about here)"

For partial report the performance of the comparison group was again characterised by a significant linear trend, $F(1,8)=22.3$, p=.001, η^2=.74, and RF reported letters in all positions at a level very close to that of the comparison children.

Discussion of RF's results from detailed assessments

Assessment of lexical and sublexical processes for spelling indicated that RF's spelling of nonwords was not impaired. However, for irregular words, performance was significantly worse than that of the comparison group. Analysis of RF's spelling errors showed that the majority were phonologically plausible. In the sentence-printed word matching task with homophones RF's performance differed significantly from that of the comparison group and, importantly, the majority of errors consisted of choice of the homophonic mate of the target. This is in accordance with the results from other studies of people with surface dyslexia (e.g., Weekes & Coltheart, 1996; Brunsdon et al., 2005; Friedmann & Lukov, 2008). The findings indicate that RF has a deficit involving lexical reading and spelling processes, and that he relies on sublexical processes.

Assessment in non-literacy tasks indicated that RF did not have difficulties in phonological ability or RAN. Overall, the profile demonstrated by RF, in terms of slow word reading, poor irregular word spelling and lack of evidence of a phonological deficit, is shared with one of the two Greek speaking children reported by Douklias et al. (2010). These authors, as noted in the Introduction, argued that the pattern could be associated with surface dyslexia in a transparent but also an opaque writing system.

Stanovich, Siegel and Gottardo (1997) suggested that developmental surface dyslexia may be due to lack of exposure to print in combination with a mild phonological deficit. We investigated this possibility in RF's case with print exposure tests, even though there was no evidence that he had a phonological deficit. We did not find any significant difference in author or title recognition scores for RF and the comparison group. Thus, it is unlikely that RF's literacy difficulties can be attributed to lack of exposure to print. Developmental surface dyslexia has also been associated with poor visual memory (Goulandris & Snowling, 1991) and a specific sequential processing deficit (Romani et al. 1999). Assessments revealed that neither of these were apparent for RF.

The assessment that did indicate a deficit was a letter report task, that has been used in the past as a measure of multi-character processing ability. RF was able to report fewer letters than children in the comparison group when tested in global report. As noted in the Introduction, poor performance in letter report has been associated in the literature with developmental surface dyslexia and surface dysgraphia (e.g., Valdois et al., 2003; Valdois et al., 2011). Although RF's global report performance was impaired, partial report appeared to be unimpaired. Valdois et al. (2011) previously reported this dissociation in the case of Martial, who had mixed dyslexia and surface dysgraphia. However, the researchers concluded that Martial's performance was atypical in the partial report task when they examined accuracy according letter position in the test array. Investigation of RF's performance according to array position did not reveal atypical performance in partial report.

We noted in the Introduction that, at present, it is not clear exactly what the locus of a multi-character processing deficit is. We reviewed the suggestion of Dubois et al. (2010) that it may be due to (among other possibilities) slow uptake of visual information, limited visual storage capacity, or a deficit in the spatial distribution of attention. RF's ability to identify single letters was assessed and the results did not indicate a deficit, indicating absence of any general visual processing impairment. As far as a potential imbalance in distribution of attention is concerned, it is unlikely to be the cause of poor letter report performance in RF's case since a deficit here would also have resulted in poor performance in partial report. In terms of limited visual storage capacity, there was no indication from the results of the visual memory tasks for any impairment in this regard, which might suggest that a deficit in visual memory per se could not be responsible for RF's poor performance in global report. However, the visual memory task requirements differed from those in the global report task in a number of respects. The visual memory tasks, unlike the letter report tasks, did not involve very brief stimulus displays, and responses involved recreating the test array from a set of stimuli and distractors, rather than recall. In addition, the font size was larger in the visual memory tasks than in the letter report tasks. Finally, there were fewer items in the sequential and simultaneous visual memory tasks (but not the memory for pictures and designs tasks) compared to the letter report tasks.

A speculative explanation of RF's letter report deficit might be that he was only able to establish a weak trace in visual memory with the short stimulus display times. Such a trace would be liable to fast decay, and only be able to support recall of a few letters from the test array. This could plausibly allow for adequate performance when only one letter needed to be recalled, as in the partial report task, but poor performance when the whole array needed to be recalled, as in the global report task. Our observations of RF’s behaviour in the global report task support this suggestion: he frequently reported two or three letters from the array and then gave up. A weak visual memory trace such as that proposed above could also plausibly impair the learning of new printed word forms, leading to a reliance on laborious sublexical decoding, as appears to be the case for RF.

Intervention study

According to the investigations we carried out, the locus of RF’s impairment was with lexical reading and spelling processes, as he did not exhibit an impairment in nonword reading or spelling but showed slow word reading and difficulty in spelling irregular words. Our investigations also identified a deficit in letter report performance, as discussed above. For the intervention we aimed at improving RF’s letter report performance and to investigate whether any improvement might be associated with change in reading and spelling ability. In so doing we could test the theory that multi-character processing ability is associated with literacy skills (Nickels et al., 2010).

A pragmatic reason for targeting letter report performance was that slow reading speed was put forward as the main literacy-related concern of RF and his family and we reasoned that a multi-character processing deficit would be particularly detrimental to speed of reading in Greek, since the vast majority of words are multisyllabic. Based on the theory of Ans et al. (1998) an improvement in multi-character processing would allow for the processing of larger orthographic units and therefore should lead to faster reading due to reduction in reliance on slow serial sublexical processing. We aimed to look at the possible association of any improvement in letter report with an increase in RF’s word reading speed and accuracy. The speculative account of RF’s deficit in letter report we outlined above was in terms of a weak or degraded visual memory trace when stimulus presentation is brief. The intervention that we devised was based on the general notion that practice with arrays of increasing size might lead to a gradual increase in visual memory capacity.

Method

Pre-intervention assessment

Two pre-intervention baseline assessments of letter report were carried out, two weeks apart. Results of Baseline 1 are reported in the *Detailed assessments* section above. On this occasion, for global report RF scored 0/20 for arrays correct, and 59/100 for total letters correct. At Baseline 2, for global report RF scored 0/20 for arrays correct and 60/100 for total letters correct.

Intervention procedure

The intervention involved repeated practice at reporting arrays of increasing length. We devised three sets of arrays, Set 1 consisted of 195 two- to four-letter arrays, Set 2 195 three- to five-letter arrays, and Set 3 104 four- and five-letter arrays. The procedure for the presentation of the arrays was exactly as described for the global report task in the *Detailed assessments* section. Practice sessions lasted approximately 10 minutes and took place each day (when possible, see below).

During each practice session there were two rest periods for Set 1 and Set 2 (with 65 arrays before rest), and one rest period for Set 3 (with 52 arrays before rest).

Intervention lasted nine weeks. Target accuracy was fixed at 95%+ for Set 1, 95%+ for Set 2 and 50%+ for Set 3. RF needed six practice sessions to reach target accuracy for Set 1, ten for Set 2 and eight for Set 3. When target accuracy had been achieved for Set 2 RF spent a week without practice, in order to reduce task fatigue. Target accuracy was fixed at 50%+ for Set 3 since RF found the task very difficult and we did not want him to experience frustration. RF spent two weeks on each set and during these two weeks he practiced each set. Practice did not take place every day as if he had a test at school he could not devote time to the task. Table 8 gives a breakdown of the level of accuracy RF achieved for each array length at the end of practice with each set.

"(Table 8 about here)"

Results

Global and partial letter report accuracy

Post-intervention assessments were conducted at three time points: immediately at the end of intervention (Time 1), four months after it ended (Time 2) and eight months after it ended (Time 3). The results are given in Table 9. At pre-intervention testing, as reported previously, RF's scores for global report were significantly worse than those of the comparison group children. Inspection of Table 9 reveals an improvement following intervention, such that accuracy was no longer significantly different from that of the comparison children, either for number of arrays or total letters correct.

We carried out analyses of the extent of improvement in RF's scores, which involved comparison of his performance at Baseline 1 versus Time 1 versus Time 2 versus Time 3. McNemar's tests were used to analyse the data. The results indicated that between baseline and Time 1 there was a significant increase both for arrays correct, χ^2=9.1, p=.001 and for total letters correct, χ^2=30.03, p<.0001, whereas between Time 1 and Time 2 and between Time 2 and Time 3 there were no further significant changes (p=1). This indicates that there was improvement in RF’s global report performance following the intervention, but that there was no further improvement (or decrease in performance) once intervention stopped.

Four children from the comparison group who were tested before RF’s intervention were re-assessed at the same time that RF was given the final post-intervention assessment (at Time 3). This was in order to look for general maturation effects in letter report in the typically developing children. A summary of the results is given in Table 9. Related t-tests were used to analyse the scores for global and partial report and revealed that there were no significant differences for the comparison children. There was therefore no indication of general maturation effects in letter report performance in children of comparable age and non-verbal ability to RF over the relevant time period.

“(Table 9 about here)”

Literacy assessments

Reading and spelling tasks were re-administered to RF and the comparison group. As for the letter report tasks, post-intervention assessments were conducted at three time points: immediately at the end of intervention (Time 1), four months after it ended (Time 2) and eight months after it ended (Time 3). A summary of the results is given in Table 10. At pre-intervention testing RF's scores for word reading accuracy and latency were significantly different from those of the comparison group. Inspection of Table 10 reveals an improvement in RF's single word reading accuracy and latency following intervention, such that scores were no longer significantly different from those of the comparison group children. Pre-intervention assessment had also indicated that RF's text reading speed was slow and his spelling of irregular words was impaired. Post-intervention testing revealed that scores for both of these continued to be significantly different from those of the comparison group (at Time 3 $t_{text\ reading\ rate}(4)=9.52$, $p<.001$, $t_{irregular\ word\ spelling}(4)=9.81$, $p<.001$).

As for the letter report results, four children from the comparison group tested before intervention were re-assessed at the same time that RF was given the final post-intervention assessment in order to look for general maturation effects. A summary of the results is given in Table 10. Related t-tests were carried out on and did not indicate significant differences for any of the literacy measures between pre-intervention and Time 3 for these children.

"(Table 10 about here)"

Comparison of change in RF's word reading accuracy and latency between pre-intervention-Time 1, and Time 2-Time 3

Our failure to include a double baseline assessment for the reading and spelling tasks leaves open the possibility that the improvement that we found in RF's word reading accuracy and latency may have been due to general maturation or test-retest effects. Since the time lapse of four months between Baseline 1 and Time 1 and between Time 2 and Time 3 was equivalent then it was possible to compare change in performance for these two time periods – a larger difference in the former would be an indication that the intervention was responsible for the improvement[2].

Two sets of comparisons were made, one for latencies and one for accuracy. A paired sample t-test was conducted to see whether the difference for latencies was significantly different across the two time periods (mean latency Time 1- Baseline 1 = 686, s.d.=582, mean latency Time 3-Time 2 = 129, s.d.=296). The result revealed that the difference in latencies between Baseline 1 and Time 1 was significantly greater than that between Time 2 and Time 3, $t(38)= 5.3$, $p<.0001$. McNemar's tests were used to analyse the significance of change in accuracy across Baseline 1-Time 1 and Time 2-Time 3. The change Baseline 1-Time 1 was highly significant (p=.008), while the change Time 2-Time 3 was not significant (p=1).

Summary of intervention findings

The assessments conducted after the intervention revealed significant improvement in global report for arrays and total letters, and improvement was also observed in reading accuracy and latency for single words. When RF was asked if he had noted any change in his reading after the intervention he reported that he now found it easier to read subtitles on the television screen for foreign language programs.

General Discussion

The case study involved a monolingual Greek child with reading and spelling difficulties. RF exhibited a deficit in reading, both in terms of accuracy and reading rate, in a standardised test. Efficiency of lexical and sublexical reading and spelling processes was assessed through word and nonword reading and spelling tasks. RF showed slower reading of words and less accurate spelling of irregular words than an age matched comparison group. However, reading and spelling of nonwords was not impaired. Qualitative analysis of spelling errors revealed that the majority of these were phonologically plausible. Assessment of phonological ability, RAN and visual memory did not reveal difficulties.

Douklias et al. argued that since, for reading, Greek does not have irregular words, developmental surface dyslexia is manifested in that language by slow word reading and poor irregular word spelling, in the absence of a severe phonological deficit. RF showed this pattern and, in addition, the predominance of phonologically appropriate misspellings and high rate of homophone choice in a printed word-sentence matching task reinforced the picture of a selective lexical processing deficit. Unlike the two surface dyslexic children in the study of Douklias et al., RF did not show an impairment of RAN. Further investigation of the association of surface dyslexia/dysgraphia and RAN deficits seems warranted.

We investigated a range of potential difficulties associated with RF's literacy problems, including a phonological deficit, a visual memory impairment and lack of exposure to print. However, it needs to be acknowledged that there are still other potential deficits that were not assessed in the present study. Ramus and Ahissar (2012) discuss diverse proposals, such as abnormal temporal sampling and anchoring difficulty, as explanations of developmental dyslexia. Other possible explanations put forward have to do with difficulty in the perception of phonemes (Ramus & Szenkovits, 2008; Cornelissen, Hansen, Bradley, & Stein, 1996), and prosody perception (Goswami et al. 2011). Facoetti et al. (2008) reported that dyslexic participants are impaired in attentional engagement/disengagement. Since these alternative potential causes were not investigated one cannot exclude a possible deficit in these processes.

However, the results of the intervention study indicated that the deficit in multi-character processing that we identified was associated with RF's literacy difficulty. The training was found to be effective in that improvement in letter report was observed immediately following the intervention, and the improvement was sustained, as demonstrated by testing four and eight months later. A significant improvement in word reading accuracy and latency was also found following the intervention, and this improvement was found to be sustained in the follow-up assessments. Previous interventions for slow reading speed (e.g., Judica, et al., 2002; Hayes et al., 2004) have included a reduction in presentation time of words over time, with the aim of reducing reliance on time-consuming sublexical processes. It may be that training in letter report and presentation-time reduction both bring about a change to use of larger processing units. It will be informative to compare the effects of different types of training in future studies.

Although a small improvement in text reading rate was observed in the standardised reading test following intervention, it was not a significant gain. The improvement in single word reading latencies may need to be more marked than that shown by RF in the present study in order to produce notable gains in speed of reading text. We also observed a slight improvement in spelling accuracy for irregular words, but again this was not a notable gain, and performance remained significantly worse than that of the comparison group when assessed following the intervention. It is plausible that change in irregular word spelling accuracy is observed some time after improvement in letter report, since presumably the establishment of lexical representations necessary for accurate irregular word spelling will be a slow, incremental process. Indeed at the eight-month follow-up assessment RF showed continued gains in spelling irregular words. However, this improvement did not produce spelling performance on a par with that of comparison children. Previous training studies with surface dysgraphic children involving repeated presentation of words with flashcards and use of mnemonic spelling techniques have been effective in improving spelling performance with irregular words (e.g., Brunsdon et al., 2005). Further training studies involving a comparison of alternative types of intervention will be critical for pinpointing the techniques that are most effective for different types of presenting problems. For the moment, we can say that the intervention appeared to bring about an increase in word reading speed and accuracy, and reading speed was reported as significantly problematic for RF prior to the intervention.

We turn next to consideration of how the improvement in letter report may have come about. Of the explanations we reviewed for a deficit in letter report performance earlier, slow uptake of letter information and imbalance in the distribution of spatial attention do not seem plausible candidates in RF's case. This is because deficits in either of these would be likely to have had a detrimental impact on partial report, and we did not find any evidence of poor performance in partial report.

We proposed instead, that RF's difficulty is better explained by a weak or degraded visual memory trace under conditions of brief exposure time. Since reading involves relatively brief fixations on printed letter strings then such a deficit could plausibly impede the learning of new printed word forms. A fast-decaying trace would make consolidation of representations in the lexical orthographic store difficult. Since our assessments indicated that RF had good phonological processing ability, which is an important core skill for the acquisition of grapheme-phoneme correspondences, we suggest that he came to rely on sublexical processing for reading and spelling, in the face of the difficulty with lexical processing, over the course of learning to read and spell. However, we acknowledge that it is impossible to tell whether RF may have had a different type of problem (for example, a phonological deficit) at a younger age. Our interpretation must remain speculative at this point, and in addition, as acknowledged above, we did not assess for other possible deficits that might explain his literacy difficulties.

An explanation such as the one proposed could possibly be verified by further testing with children showing the same pattern of performance that RF showed prior to intervention. If it is correct then we should be able to demonstrate in letter report a point at which, with increasing array exposure time, performance is equivalent to that of comparison children. In addition, detrimental effects of masking on letter report under optimal viewing conditions would be likely. Further investigation of the different possible causes of multi-character deficits seems important.

It will also be important to investigate in more detail the reasons for the improvement in reading following intervention. We found an increase in single word reading speed and accuracy, and we have hitherto equated fast single word reading with lexical processing. However, we cannot be sure whether the improvement was a result of change from sublexical to lexical processing, since an increase in word reading speed and accuracy could have arisen from improvement in efficiency of sublexical processes (for example, due to improved storage of letters for conversion to sound, or use of larger units for print-to-sound conversion). Further testing using experimental techniques such as priming and visual search (see, for example, Ktori & Pitchford, 2009), or examination of the effect of word length on reading (see, for example, Weekes, 1997), would be informative in addressing the issue of whether intervention results in a switch from sublexical to lexical processing.

We suggest that the results add to a growing literature indicating that detailed theoretically-based assessment is vital in the development of effective interventions for literacy difficulties, and they also reaffirm the important role of intervention studies in testing hypothetical associations of cognitive processes.

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Appendix A

List of 50 nonwords used in the 1 minute nonword reading test

ωζέπα	ταναστίκι	Τζαλεγκακού	ηκηθοβυλόμου	αδιγαποκιντόπο
αεράπι	μιαγομπός	Ητευσκαραπό	σειφτεθράκου	ποτευνοκιάδιμα
ηχναρό	ραρμπούκα	Σοροδαρκάμι	χιαντζάρενου	σινεμοιηπόνοκι
αχετρής	εμανιγακά	Σολιάνουπης	οτηνικοταύμα	σονεμονυθεύτακο
κονεθάμι	απευρούκας	Ωχετράτακας	οντρεδοκεύμα	στρικανολαμπόμα
αδαμόβδι	οταληδόπης	Σοροδιμερτά	οτιζεπατρίπος	τσονεμεικιαραφής
ασμιθακό	ηδιβατσάκι	Αμοστράτακη	σοτσειταμέχρα	
ιοραύτου	ολόκεμπρης	Οναπλορέσας	σονιούνγκιπος	
γιοβλίβας	ονούβραλος	Πευσκέκαυνο	στραπαλούντος	
αδιράτσακου	ηκαυτζαμπό	Σονεσμιθάκης	σονευσμίχυτης	
οιματζόμα	σοτεαρταχής	σηραχομελοπό	τονεκηθαμολάκι	

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"Table 1": Standardised scores in background assessments for RF and the comparison group (scores in bold are raw scores, standard deviations are in parentheses)

	RF	Comparison group mean
Non-verbal reasoning[α]	117	111 (0.88)
Arithmetic[b]	140	129 (2.1)
Digit Span[c]	115	104 (0.3)
Vocabulary[d] (max correct:174)	**154**	**146** (6.2)

[α]Matrix Analogies Test (Naglieri, 1985b), [b] and [c] arithmetic and digit span subtests from WISC-III (Georgas et al., 1997), [d] PPVT (adapted for Greek, Simos et al., 2011).

“Table 2”: Standardised scores for reading and spelling assessments for RF and the comparison group (scores in bold are raw scores, standard deviations are in parentheses)

	RF	Comparison group mean
Standardised measures		
Reading comprehension [a]	108	119 (1.1)
Morphological awareness[a]	125	119 (0.59)
Text reading rate[a]	67***	125 (4.8)
Reading accuracy[a]	81****	108 (±1.3)
Single-word spelling-to-dictation (max correct = 60)[c]	**16****	**51 (6.0)**
Spelling based on written text (max correct = 100)[d]	**67****	**96.7 (2.0)**
Coherence based on written text (max score = 50)[d]	**45***	**48.6 (0.5)**
Experimental measures		
Single-word reading latency (msecs)[a]	**1719***	**887 (235)**
Single-word reading accuracy (max correct = 53)[a]	**42*****	**51.7 (0.95)**
Nonword reading latency (msecs)[a]	**1802**	**1112(334)**
Nonword reading accuracy (max correct = 24)[a]	**16**	**19.5 (1.9)**
Nonword reading rate[b]	**17**	**23 (5.4)**

[a]= Reading Test Alpha (Panteliadou & Antoniou, 2007) [b]=Experimental task of nonword reading rate, [c]= Single word spelling to dictation test (Mouzaki et al., 2007) [d]= Diagnostic test of difficulties in written production (Porpodas et al., 2007), * = p<.05, ** = p<.01, *** = p<.001, **** = p<.0001

"Table 3": Number correct for RF and comparison group in irregular word and nonword spelling (standard deviations are in parentheses)

	RF	Comparison group mean
Irregular words (max correct=20)	2****	16 (1.9)
Nonwords (max correct=40)	39	39 (1.2)

**** = p<.0001

“Table 4”: Scores in assessments of phonological ability and RAN for RF and the comparison group. Times recorded for the spoonerisms and word reversal tasks involve time to complete the task. Times for the RAN tasks involve time to complete naming the task stimuli (standard deviations are in parentheses).

	RF		Comparison group mean	
	Accuracy	Time *(secs)*	Accuracy	Time *(secs)*
Blending (max. correct = 32)	30	-	30 (2.7)	-
Spoonerisms (max. correct = 20)	19	54*	18 (2.9)	141 (43)
Word Reversals (max. correct = 12)	7	76	6.1 (1.5)	118 (27)
RAN[a] Pictures		39		38 (5.1)
RAN[a] Digits		20		21 (4.7)
RAN[a] Letter sounds		15		14 (3.1)

[a]Rapid automatized naming, *$p<.05$

“Table 5”: Number of choices made from the four alternatives provided in the sentence-printed word matching task for RF and comparison group (standard deviations are in parentheses)

	RF	Comparison group mean
Target (max correct= 40)	28****	38 (2)
Homophonic mate	10**	2 (2.1)
Pseudohomophone	1	0
Visually similar word	1	0.2 (0.4)

** = *p*<.01, **** = *p*<.0001

“Table 6”: Visual memory task scores for RF and the comparison group (standard deviations are in parentheses)

	RF	Comparison group mean
Pictures (max correct = 32)	31*	22 (3.8)
Designs (max correct = 32)	20	19.7 (3.6)
Simultaneus memory (max correct = 12)	10	8 (1.8)
Sequential memory (max correct = 12)	11	8 (1.7)

*p<.05

“Table 7”: Results for RF and the comparison group in the letter report tasks (standard deviations are in parentheses)

	RF	Comparison group mean
Global report arrays (max. correct = 20)	0.00**	9.5 (2.5)
Global report total letters (max. correct = 100)	59.0***	85 (4.6)
Partial report (max. correct = 45)	40.0	38.2 (1.9)
Letter identification accuracy (max. correct=45)	45	44.4 (0.74)
Letter identification (msecs)	773	735 (84.2)

** = p<.01, *** = p<.001

“Table 8”: Number of practice sessions per set and score (percent correct) achieved by RF for strings of different lengths

	Total sessions	2Letters	3Letters	4Letters	5Letters
Set 1	*6*	100	100	89.8	-
Set 2	*10*	-	100	95.3	36.3
Set 3	*8*	-	-	100	65

“Table 9”: Pre- and post-intervention performance in the letter report tasks for RF and the comparison group (standard deviations are in parentheses)

	Pre-intervention		Post-intervention			Comp. Group mean	
	B1	B2	Time 1	Time 2	Time 3	B1	Time 3
Global report arrays (max. = 20)	0*	0*	11	10	12	8.5 (2.6)	7.8 (1.8)
Global report total letters (max. = 100)	59**	60**	91	91	90	84.5 (5.0)	86 (2.8)
Partial report (max. = 45)	40	-	41	42	43	38.7 (.5)	40 (3.1)

B1= Baseline 1, B2= Baseline 2, * = p<.05, ** = p<.01, *** = p<.001, *** =p<.0001.

“Table 10”: Pre and post-intervention performance in reading and spelling assessments for RF and the comparison group (numbers in bold are standard scores, standard deviations are in parentheses)

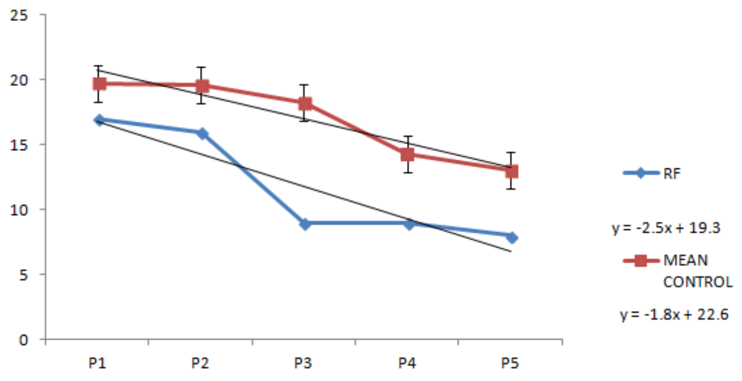
	Pre-intervention	Post-intervention			Comp. group mean	
		T1	T2	T3	Pre-int.	T3
Standardised measures						
Reading comprehension[a]	**108**	**108**	**113**	**115**	**119 (1.1)**	**119 (1.2)**
Text reading rate[a]	**67****	**68****	**76****	**76****	**125 (4.8)**	**125 (4.6)**
Experimental measures						
Single word reading accuracy (max correct= 53)[a]	42***	50	50	52	51.7 (.95)	52.5 (.57)
Single word reading latency (msecs)[a]	1719**	1039	1228	1092	887 (235)	756 (132)
Nonword reading accuracy (max correct = 24)[a]	16	17	19	23	19.5 (1.9)	18 (4.1)
Nonword reading latency (msecs)[a]	1802	1105	1230	1084	1112 (334)	1007 (212)

Irregular word spelling[b] (max correct = 20)	2^{****}	-	7^{***}	9^{***}	18 (.82)	18 (1.9)
Nonword spelling[b] (max correct = 40)	39	-	39	40	39 (.96)	40 (.50)

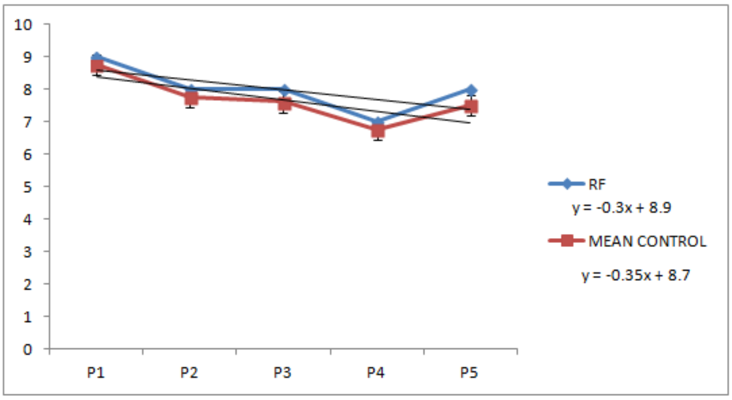
[α] Reading Test Alpha (Panteliadou & Antoniou, 2007), [b] Loizidou-Ieridou et al. (2009), * = $p<.05$, ** = $p<.01$, *** = $p<.001$, **** = $p<.0001$

Figure 1: Letter report accuracy according to letter position for RF and the comparison group

a. Global report



b. Partial report



Note: P=position

Footnote:[1] The first author, a native speaker of Greek, devised all the experimental tasks reported in the paper. Computer-presented tasks were programmed using the DMDX programme developed by Forster and Forster (2003).

[2] We are grateful to one of the anonymous reviewers for this suggestion.